A COMPACT PROTOTYPE OF AN OPTICAL PATTERN RECOGNITION SYSTEM

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ABSTRACT

in the Technology 2006 Case Studies/Success Stories presentation, we will describe and demonstrate a prototype of a compact optical pattern recognition system as an example of a successful technology transfer and continuing development of state-of-the-art know-how by the close collaboration among government, academia, and small businesses via the NASA SBIR program. The prototype consists of a complete set of optical pattern recognition hardware with multi-channel storage and retrieval capability that is compactly configured inside, a portable 1'x2'x3' aluminum case. The prototype invoked advanced laser holographic and opto-electronic methods which have important government and commercial applications including I mar and Mars exploration robotics vision, automatic target detection, finger prints identification, and industrial inspection automated quality control operations.

INTRODUCTION

Since the advent of the Vander Lugt technique for the synthesis of an optical matched spatial filter (MSF)[1], there have been many demonstrations of this pattern recognition method on diverse classes of input data. Owing to the quasi-periodic structures (of the ridges and valleys) such as in the example of the case of human fingerprints, it seems natural to examine these patterns in the frequency domain. In fact, several schemes for this purpose have been proposed and experimentally verified in the past. These include Vander Lugt correlators[2,3], joint transform correlators[4,5], and an optical Fourier transform with a ring-wedge detector[6,7]. Generally an all-optical Vander Lugt correlator is simpler and less expensive in comparison with the hybrid system using a computer and a spatial light modulator (SLM), and is thus more desirable for an economic pattern recognition system with moderate accuracy.

The basic Vander Lugt correlators have usually been divided into two categories: the classical 4f system and the scaling correlator[8]. in the latter the distance between the object plane and the filter plane may be changed to match the wavelength difference in recording and reconstruction. In the practical performance of a correlator, the effects of different factors on correlation degradation have been investigated[9,10]. The perpose of this paper is to shown how amulli-channel optical pattern recognition prototype may be packaged in a compact system and to discuss the poterntial applications of the system.

A COMPACT BREADBOARD PROTOTYPE

System Architecture and Procedure of Operation

The system architecture and procedure of operat ion of a breadboard of a compact prototype arc. dc.scribe.d below.

Figure 1 is a system diagram of the compact breadboard prototype. The system is designed to be arranged on a 18"x30"x0.5" mini-bench mounted in an aluminum case. in the. optical set-up, a laser beam from a He-Ne laser is divided into two beams, an object beam and a reference beam, by a beam split ter. The object beam is collimated by a spat ial filter and lens combination and illuminates the input pattern. A holographic optical element is used to Fourier transform and multiplex the, object beam into a **5x5** array at its focal plane where a holographic matched filter is recorded. A convergence reference beam is used to interfere with the object beam at the matched filter plane. During the recording of the matched filter, only onc object beam at a time is used with the reference beam to make the hologram until all **25 channels** are recorded. The developed hologram becomes the multi-channel matched filter. in the reading process, the matched fi lter is replaced at exactly at its original location and the reference beam is turned off. The signal represent ing the correlat ion bet ween the input pattern and the pattern used in the recording of the matched filter can be found at the focal plane of the regenerated reference beam where a CCD photo-detector is placed. The experimental test results showed that high signal to noise ratio can be obtained.

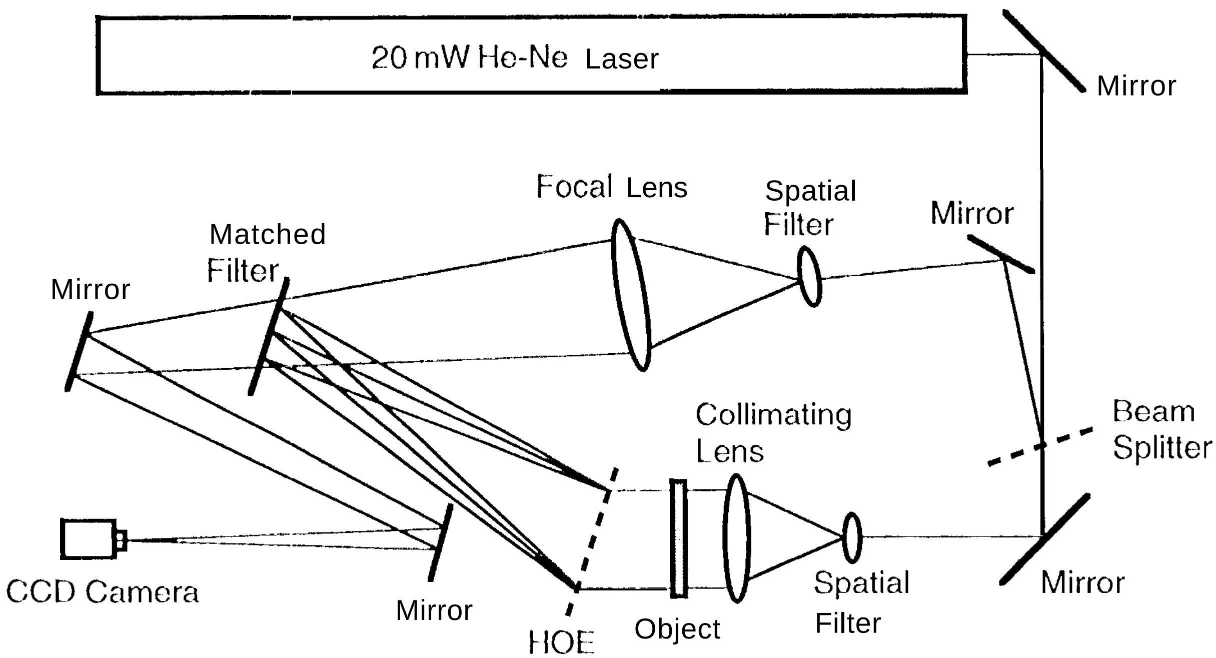

Figure 1 A system diagram of the laboratory breadboard prototype.

Theoretical Basis

Assuming a convergent wave passing through plane P_1 and focusing at a certain point $S(x_s,y_s)$ in plane P_2. According to the paraxial approximation, the distance from an arbitrary point (x_1,y_1) in P_1 to point S should be

$$r = \sqrt{z^2 + (x_1 - x_s)^2 + (y_1 - y_s)^2} = z + \frac{(x_1 - x_s)^2 + (y_1 - y_s)^2}{2Z} + \cdots \tag{1}$$

where z is the distance between the two parallel planes P_1 and P_2. If

$$(x_1 - x_s)^2 + (y_1 - y_s)^2 << Z^2, \tag{2}$$

we may take into account only the first two terms in Eq. (2) and neglect others. However, when the oblique angle θ is not very small (e. g., >15°), the condition above may not be satisfied. In this case we can use the following nonparaxial representation,

$$r = \sqrt{R^2 + x_1^2 + y_1^2 - 2x_1x_s - 2y_1y_s} = R + \frac{x_1^2 + y_1^2 - 2x_1x_s - 2y_1y_s}{2R} + \cdots \tag{3}$$

where R = OS. The similar requirement to keep only the first two terms in Eq.(3) is

$$x_1^2 + y_1^2 - 2x_1x_s - 2y_1y_s << R^2, \tag{4}$$

which is much less stringent than Eq. (2).

Based on this nonparaxial approximation, the light distribution at plane P_1 can be expressed as

$$u(x_1,y_1) = \exp\left[\frac{i\pi}{\lambda R}\left(x_1^2 + y_1^2 - 2x_1x_s - 2y_1y_s\right)\right], \tag{5}$$

where all constants independent of x_1 and y_1 are and will be ignored throughout this paper without loss of any physical meaning.

Employing the Fresnel diffraction theory, we can derive the light field distribution in plane P_2 when a convergent wave passes through a mask at plane P_1 with a complex amplitude transmittance $t(x_1,y_1)$ as

$$u(x_2,y_2) = \iint t(x_1,y_1)\exp\left\{-i\frac{2\pi}{\lambda R}\left[(x_2 - x_s)x_1 + (y_2 - y_s)y_1\right]\right\}dx_1dy_1, \tag{6}$$

which is simply a Fourier transform of $t(x_1,y_1)$ with a certain scale relation between the space and frequency domains.

Breadboard Prototype Packaging

The completed package of the breadboard prototype are shown in Figs. 2 and 3. In Fig. 2, the essential optical components including a He-Ne laser, spatial filters, mirrors, and holographic optical components for the multi-channel optical beam splitting are shown to be tightly fastened to a 18 inch by 30 inch aluminum breadboard. We have performed experiments in the prototype with repeated tests. It can be shown that the correlation signal can still last in the system after many days. We then closed the aluminum case (Fig,. 3) and transported the case around with vibrations. The test results showed that the correlation signal may disappear due to the strong vibrations that the case experienced and the displacement of the micron sized pinholes in the spatial filters. However, it can be shown that the signals can be easily restored by making another matched filter. The filter can be made in situ. Therefore the prototype accomplished the vital proof that this prototype is a viable and practical system.

Applications

As shown above., the compact prototype offers significant potential capability to perform parallel recognition of input patterns or vector sets originating from multiple sensors, which measure either identical or different types of signals. This capability has direct potential applications in several fields, including parallel database search, image and signal understanding and synthesis, and robotics manipulation and locomotion, in addition to real-time pattern recognition.

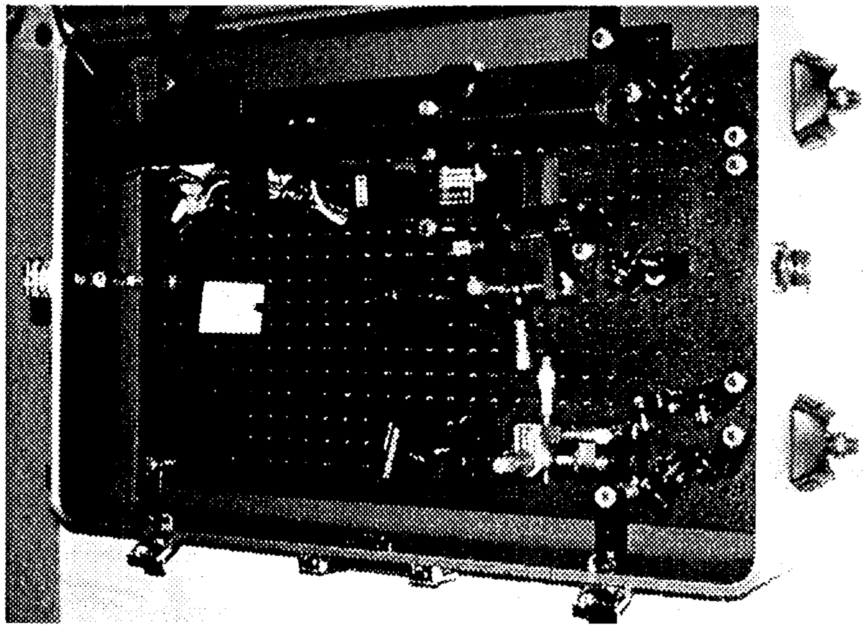

Figure 2 A photograph showing the inter-ior optical arrangement of a breadboard prototype.

Figure 3 A photograph showing the exterior view of a breadboard prototype.

In the following sections, wc examine some of the possible applications that may utilize the capability of the prototype system.

Real Images

The most obvious application of the prototype is a neural pattern recognition tool, for usc in NASA and/or industrial environments. The input patterns may be directly fed to a spatial light modulator from a standard or nonstandard video camera. This input may be one of a known sct of potential inputs. The set of known potential inputs may be stored in matrix form. Thus, the input pattern, which may contain noise or variations, through optical processing of the prototype, will identify a known rcfcrencc pattern, fi any, at the output plane. This output may either bc presented for dirccl visual confirmation.

One example of such a utilization of the prototype is for robotics vision. The propotype offers the capability of a relatively compact optical processing system to handle imperfect visual input and draw conclusions based upon its own reference library of patterns. This may allow mal-time vision analysis to be performed, which could bc translated to independent robotics locomotion and environmental interaction,

Related Vector Sets

The second major area in which the prototype might bc well utilized is in the processing of large and complex data sets, either from a single detector or source, or from more than one detector simultaneously.

Known data patterns which arc to bc searched for may first bc encoded. 'l'he input S1 .M may then be fed continuous information from detectors aimed at the field(s) of intc.rest, and prototype will in parallel compare each input frame with all of the stored reference data patterns. Any input data frame which contains a pattern sufficiently similar to one of those stored will result in the ideal reconstruction of only that pattern at the output plane.

Not only does this allow for direct large scale compares and recognition of data to be accomplished in parallel, but it also presents the capability of inferring information from the input, and establishing new recognition rules to be sought and found. This is due to the fact that each input pattern will result in some output that indicates how the input data pattern compares and is similar or dissimilar to, the data patterns stored. Thus one may attempt to "teach" the prototype to recognize any and all levels of data patterns present in the incoming signals, both on the level of the discrete data itself and on higher levels of data field. Documentation of the prototype output in a training mode may allow the repeated ability to infer information from the input of previously unusable or unseen data patterns.

ACKNOWLEDGMENT

The research described in this paper was partially carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The effort of Standard International, Jnc. was carried through funding from NASA/Jet Propulsion Laboratory Small Business Innovative Research (SBIR) under contract NAS 7-1307. The collaboration with the University of California, Santa Barbara is appreciated.

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